Numerical Weather Prediction

New Mesoscale Model Configuration for the CRAY T3E. Report on tests

Forecasting Research Technical Report No. 228

Clive Wilson and Ian Culverwell

email: nwp_publications@metoffice.com

©Crown Copyright

New Mesoscale Model Configuration for the CRAY T3E. Report on tests to identify "best domain and resolution"

C Wilson and I Culverwell, NWP Division
December 1997

1. Introduction

The extra computer resources made available by the acquisition of the CRAY T3E allows the UK mesoscale configuration of the Unified Model to be enhanced, within an overall factor of four increase in cost. The agreed technical solution to the NWP user requirement envisaged the new mesoscale model being run 4 times per day to T+36, coupled through its lateral boundaries to the enhanced (60km, 30 level) global model; these would run in parallel so that the mesoscale products would both benefit from more "up-to-date" boundary data and be available by 2h 30min after nominal analysis time. The new domain and resolution for the mesoscale model were to be determined in consultation with users and after tests to identify whether extra resolution or greater areal coverage were more beneficial. This report summarises the results of those tests and makes a recommendation for the choice of area and resolution.

To be consistent with the 30 level global model the mesoscale levels need to be increased to 38 so as to maintain the enhanced resolution of the current mesoscale levels in the lower atmosphere, and secondly so that the model resolution above 500 hPa is no worse that the (driving) global model (Fig. 1.1).

User requirements place the following constraints on possible horizontal domains/resolutions:

- CPU time no greater than four times present value (for an equivalent length forecast run)
- coverage of surge, current model (OPMOD) and a new UK coastal wave model sea points
- coverage of QNH areas 16,18 and 21
- extension to south (possibly to Pyrenees) to improve "Spanish Plume" type cases and other (mostly summer) developments from south
- extension to south to take advantage of the possibility that continental radar data will be available at a future date.

An additional technical constraint on the number of rows and points arises from the need for efficiency with fast Fourier transforms which are used in the proposed new analysis (3DVAR).

A number of potential configurations were tested in forecast only mode for six cases in (an earlier) stage 2a of the project (Culverwell, 1997). These were initialised from low resolution LAM files, but included ancillary surface and orography fields derived from high resolution source data. The cases were mostly only assessed subjectively. The conclusions of these forecast only tests were:

- The model was stable in all suggested configurations
- 38 levels caused no problems
- Most configurations and runs were within the factor 4 target
- Convective parametrisation is well behaved for resolutions down to 12km
- A problem with rough PMSL fields at edges of domain caused by fine scale orography was solved by extending driving model (LAM) orography inwards
- There was a slight benefit from westward extension of domain for a winter storm case
- There was no apparent problems with coupling to a driving model a grid length more than 4 times larger
- There was slight benefits from increased resolution in distinguishing nearby rainbands and an intense convective line
- Subjectively there was little improvement in forecasting a radiation fog case although objectively the higher resolution was better

Following a meeting of the project board the largest domain with the same horizontal grid length (0.15 degree) as currently operational was rejected from further consideration, since the westward extension would be well-handled by the increased global resolution model, which would be the main forecasting guidance of developing systems.

The three remaining potential domains and resolutions (Fig. 1.2) have been tested in a number of case studies with data assimilation in order to select the "best" domain. The results are summarised below. The configurations used are:

- Control: 92 rows x 92 points, resolution 0.150 degree (16.7km), operational area ~47°N to ~60°N
- Test2: 162 rows x 156 points, highest resolution 0.105 degree (11.7km), ~47°N to ~64°N
- Test3: 182 rows x 146 points, resolution 0.125 degree (13.9km), ~41°N to ~64°N
- Test5: 182 rows x 146 points, resolution 0.110 degree (12.3km), ~44°N to ~64°N

All configurations used a rotated latitude longitude grid with rotated pole at 37.5°N, 177.5°E.

2. Experimental test procedure

The original plan envisaged using the new rerun suite to test full data extraction and assimilation over the candidate domains for two continuous periods for winter and summer. The delay in development of the rerun suite and *especially* the inability to extract observations for past cases for the full areas of the new domains led to abandoning this in favour of cases studies for a wider variety of synoptic types.

Each test consisted of a short assimilation of 6 hours followed by a 30 hour forecast. The initial data was interpolated from a LAM analysis for all the test domains *and the control operational domain.* The observations were assimilated from mesoscale ACOBS files which were used operationally and were retrieved from the archive. In order to be used with 38 layers the radiosonde observations were interpolated from the 31 layers. Figures 2.1 and 2.2 show this to be a reliable procedure for potential temperature and westerly wind respectively. Also because surface pressure and temperature are preprocessed to the current orography it was not possible to assimilate these observations for the new domains and resolutions due to the change in orography. Although the change in height is generally small a test including the assimilation of surface pressure and temperature showed this could generate spurious noise. MOPS cloud data was obtained from the operational LAM files, which are based on a cloud analysis at 45km horizontal resolution and 16 wet layers (out of 19). Whilst this is poorer resolution than the operational mesoscale MOPS it allowed an assessment of how an extended domain might benefit from extra data. Again a vertical interpolation (Fig. 2.3) was used to obtain cloud data for the new layers (35 of which include moisture). If a new layer did not fully overlap one of the 16

input layers it was set to zero cloud fraction. This could mean a slight reduction of total cloud. For the first cases studied there was no latent heat nudging applied, but was included in the later cases when suitable rainfall analyses files were obtained, covering the operational mesoscale domain.

3. Cases chosen

Cases for a variety of different weather regimes were selected with data times as follows:

1. Spanish plume, 12Z/060697
2. Spanish plume again, 06Z/060697
3. Winter storm, 00Z/240297
4. Strong cross-orographic flow and radiation fog, 00Z/210197
5. Organised convective bands, 06Z/120597
6. Rain/snow boundary, 00Z/191196
7. Sea breeze convergence storms, 00Z/170697
8. Rainband where latent heat nudging beneficial impact operationally, 12Z/110697
9. Wimbledon middle Sunday, 12Z/280697
10. Sea breeze convergence storms and Rouen flood, 00Z/160697
11. Fog, 06Z/101196
12. Frontal rainband were latent heat nudging poor impact operationally, 12Z/250697
13. Still spring day, fog misforecast, 00Z/310397
14. Intense convective storm (Leatherhead), 06Z/080797

Latent heat nudging was applied in all cases except 1 and 3 to 6. There is a bias in selection toward summer cases over winter/spring (8:5), which is a consequence of i) the question whether data to the south (MOPS only in the tests) assimilated at high resolution would be beneficial; and ii) more interest and familiarity with recent cases.

4. Subjective assessment

(1) "Spanish Plume", DT 12Z/060697

Though this was not a true Spanish Plume, the very warm and moist continental air associated with the frontal depression coming up from the south-west did lead to thundery outbursts sweeping over southern/central England during the evening of the 6th (see Fig 4.1.1). It was therefore deemed a good test of the impact of extending the mesoscale southern boundary.

The 4-up chart of the control, test2, test3, and test5 runs at T+0, shown in Fig 4.1.2, demonstrates that the two runs with the extended southern boundary are in fact worse at capturing the rain coming in from the SW. It seems therefore that the LAM driving model is having more impact at this time than the assimilation of MOPS data on the higher resolution grids (bear in mind that it is the same MOPS data going into the LAM and the MES models, albeit interpolated onto different levels). This situation continues at T+6 (Fig 4.1.3). By T+12 (Fig 4.1.4) the models are similar, while at T+18 (Fig 4.1.5) the two extended area models match the radar picture better. We think this is because they allow development over the continent at the mesoscale resolution, and that this showery activity then drifts northwards without interference from the low resolution driving model.

Overall conclusion: Impact of LAM BCs stronger than resolution or domain size effects.

(2) "Spanish Plume Again; Earlier Data Time", DT 6Z/060697

To shed some light on the curious results of the previous case, we decided to rerun this case starting six hours earlier.

The initial analysis is now similarly good in all cases (Figs 4.2.1 and 4.2.2). At T+6 the forcing by the LAM boundary conditions, so beneficial to the "short domain" models in the previous case, is now having a deleterious effect: the rain in these models is too far advanced up the SW Peninsula (Figs 4.2.3 and 4.1.1). At T+12 the intense convection over southern England is missed by the control and test2, and present (though far too weak) in the "long domain" models (Figs 4.2.4 and 4.1.1). At T+18 the rain has been pushed too far NE in the short domain models

(again probably a result of overly strong forcing from the LAM), while the rain remains over east Anglia in the other two models, which also hint of rainfall north of the Isle of Wight (Figs 4.2.5 and 4.1.1). All the models are fairly poor beyond this time.

Overall conclusion: Extending the southern boundary has a beneficial effect.

(3) "Winter Storm", DT 0Z/240297

A intense (<950mb) low to the NW of the UK drifted slowly eastward during the day, while another low initially to the SW of Ireland intensified and swept across the UK bringing heavy rain and gale force winds over southern/central England during the evening (Fig 4.3.1). The 4-up PMSL patterns at this time (Fig 4.3.2) shows that test3 comes closest to capturing the depth of the secondary low (968mb at 18Z), and more sharply defines the main low (analysed as two lows of 946mb and 950mb on the NMC chart at this time). We think this is because the slightly extended western boundary of test3 allows it to fully capture the main low during the assimilation period (Fig 4.3.3 shows the pmsl at T+6), with less degradation by the low resolution boundary conditions.

Overall conclusion: Fortuitous benefit from slightly extended western boundary in test3.

(4) "Cross-orographic Flow", DT 0Z/210197

Although initially tried as a test of the impact of strong flow over high ground (Norwegian mountains, the Alps, the Pyrenees) in the extended domains, this case doubles as a test of fog formation and retention, because high pressure over the UK led to a radiation night. In fact the operational 06Z run had "too much fog early on and again by midnight" (according to NMC), and the operational 00Z run was similarly flawed.

The fog probabilities at 6Z/210197 (Fig 4.4.1) and 0Z/220197 (Fig 4.4.2) are very similar.

Overall conclusion: No benefit from increased resolution or larger area.

(5) "Organised Convection", DT 6Z/120597

Bands of rain passed SE over the country during the afternoon (eg see radar picture at 12Z, Fig 4.5.1). This case has been run on only two models: the control, and test4, which uses the highest possible resolution (0.105 deg=11.7km) on the current domain. This allows us to test the sensitivity of the results to the resolution of the MOPS data, because either LAM or MES MOPS can be used on these domains.

Fig 4.5.2 compares the results obtained using the LAM MOPS (ie what is done in all the other tests), and shows more concentrated and 'fractured' rainfall in the high resolution run. Fig 4.5.3 shows the corresponding runs using MES MOPS: again the high resolution run defines the rainfall pattern more sharply. Comparing the two figures shows that the rainfall is more intense when using LAM MOPS data, but similarly distributed. This lends confidence to any conclusions drawn from the other cases, which use LAM MOPS in all the models.

Note that this case has not been objectively verified.

Overall conclusion: Slight benefit from increased resolution.

(6) "Mixed Rain/Snow", DT 0Z/191196

A frontal depression passing eastward through the English Channel led to substantial snowfall over southern/central England during the morning rush hour. This was forecast well by the Nimrod system (Figs 4.6.1 and 4.6.2), but poorly by the MES, which diagnosed the precipitation as rainfall.

Fig 4.6.3 shows that the snowfall rates forecast by the test models are not significantly greater than those in the current model.

Overall conclusion: Neutral impact.

(7) "Sea Breeze Convergence Storms", DT 0Z/170697

The convergence of the sea breeze and the prevailing NE'ly set off storms over the south coast and SW peninsula during the afternoon (Figs 4.7.1 and 4.7.2). These were quite well forecast in the control run at 15Z (Fig 4.7.3), and not significantly better in the higher resolution tests. However, the precipitation over the Yorkshire coast was improved in all the test runs and strongest at the highest resolution (test2). At 18Z (Fig 4.7.4) the control precipitation is too weak, and again not significantly better in the tests (with the same exception). Streamline analysis (Figs 4.7.5 and 4.7.6[1]) shows rather more convergence (darker lines) in the higher resolution runs, although this is apparently not translated into increased precipitation except over Yorkshire.

Overall conclusion: Neutral impact.

(8) "Good Impact Latent Heat Nudging", DT 12Z/110697

This case is known to have benefited strongly from latent heat nudging (Macpherson, personal communication), which led to the northwards moving band of rain being concentrated around the Midlands and northern England at T+12 rather than being dispersed over a much wider area, in agreement with the radar evidence (Fig 4.8.1). The control puts the rain too far south at T+12, while the tests with an extended southern boundary are slightly better in this respect (Fig 4.8.3). Test2 shows some bunching of the rainfall along the rainband at this time, although this pattern becomes less distinctive later (Figs 4.8.2 and 4.8.4). There is little evidence for gridpoint convergence at the earlier time (Fig 4.8.5).

Overall conclusion: Some benefit from extending the southern boundary.

(9) "Rain Didn't Stop Play at Wimbledon", DT 12Z/280697

The forecasts made on 28/06/97 for 29/06/97 ("People's Sunday" at Wimbledon) suggested NW-ward moving rain over SW London which did not substantially materialise. Comparison of the control and tests at T+24 with the (dry) radar picture (Figs 4.9.1 and 4.9.3) shows four different

[1]The contouring package automatically draws fewer lines for the higher resolution tests which may mislead the eye for the strength of convergence. The divergence shading of the streamlines allows a fairer comparison.

but equally poor forecasts, with the current model perhaps being best. At T+27 however, test3 is probably best, although the disparity between the runs is again large (Figs 4.9.2 and 4.9.4).

Overall conclusion: Slight benefit from extending the southern boundary.

(10) "Convergence Zone Storm and Rouen Flood", DT 0Z/160697

A similar story to Case 7, although here the high resolution models (test2 and test5) seem to better handle the convergence zone storms over southern England, especially Surrey and to the south of London, at 15Z (Figs 4.10.1 and 4.10.3). Similarly at 18Z over Hampshire and Wiltshire (Figs 4.10.2 and 4.10.4). Note that none of the models predicts the downpour over Rouen evident in the last radar picture. Streamline analysis again shows more convergence in the high resolution models, test2 and test5 (Figs 4.10.5 and 4.10.6, bottom rows).

Overall conclusion: Benefit from higher resolution.

(11) "Disappearing Fog", DT 6Z/101196

The VIS satellite image at 15Z (Fig 4.11.1) shows the fog over NE England that persisted all day, but which evaporated in the operational model. The fog probabilities at this time (Fig 4.11.2) show that the test runs share this failing, with test5 perhaps giving slightly more of a suggestion.

Overall conclusion: Weak benefit from increased resolution.

(12) "Poor Impact Latent Heat Nudging", DT 12Z/250697

This case is known to have been degraded by latent heat nudging, due to the application of radar data too far beyond its validity time (Macpherson, personal communication). This produces a rather poor analysis in all the tests (Figs 4.12.1 and 4.12.3), and the runs keep in step from then on until T+30 (Figs 4.12.2 and 4.12.4), when the control and test2 runs look better.

Overall conclusion: Broadly neutral impact.

(13) "Still Spring Day", DT 0Z/310397

An anticyclone over SE England/N France led to clear skies and light winds, with fog over the south coast not clearing until late morning (eg see VIS satellite image at Ex in Fig 4.13.1). The operational model did not predict this, and instead forecast fog over the eastern English Channel. Although our control did not suffer the latter failing, it did fail to forecast substantial fog over the Bournemouth area (Fig 4.13.2). This same figure shows that none of the tests was much better at predicting this fog, although there is a hint of it in tests 3 and 5.

Overall conclusion: Neutral impact.

(14) "Leatherhead Storm", DT 6Z/080797

Over 2 inches of rain fell in Leatherhead within about an hour in the afternoon of this day (Figs 4.14.1 and 4.14.2). On the previous two days the operational model had predicted showers which did not materialise. This meant that although the control run predicted weak showers in the right place at the right time (Figs 4.14.3 and 4.14.4), their likelihood was played down in the official forecast. The last two figures show that the tests did not significantly strengthen the showers, and indeed at 18Z the control is probably best.

Overall conclusion: No benefits in any test.

5. Objective verification

All the cases were verified against observations using the NWP mesoscale verification system. This system verifies forecast data against observations made at 289 stations in the British Isles and nearby on the continent. The mean results for all cases will be summarised here. In addition the "Spanish Plume" cases were verified against the Nimrod rainfall analyses.

The results should be treated with some caution since there are only a limited number of cases, and the full impact of extra observations in the extended domains has not been assessed with the experimental method used here. The expected impact from better (more up-to-date) lateral boundary values is also necessarily absent.

Temperature

The highest resolution, test2, has a slightly reduced cold bias, particularly early in the forecasts and the rms errors are generally lowest for this configuration (Fig 5.1). However the other test configurations extended to the south are generally slightly worse than the control, despite the increase in horizontal resolution.

10m winds

For all the tests the wind speeds are on average generally lower, although the biases are mostly better out to T+18, whereas the control winds are mostly too strong (Fig 5.2). However the rms wind speed errors in the control and the tests are very similar, as are the bias and rms vector wind errors, defined as |**v**(forecast) - **v**(observed)| (Fig 5.3). Hence the conclusion is that the impact is mostly neutral. (The high values of the vector wind errors result from verifying against stations that are near the coast or whose height differs from that in the model by more than 100m. When these are removed from the station list the bias and rms vector wind errors are reduced to around 2-3 m/s.) The sub-grid orographic roughness has been derived from the same source data (100m) and is not greatly different at the different resolutions. It is rather disappointing that the extra detail of the resolved orography has not been more evidently advantageous.

Fog probability

Fog probability forecasts (essentially the cloud fraction at 1.5m) are verified by comparison with the reported visibilities, with visibility less than 1000m being assigned a fog probability of unity, and zero otherwise (ie a 'Brier'-type score). The overforecasting bias is reduced with higher resolution (Fig 5.4) especially for the finest grids (test2 and test5) with similar improvement to rms errors.

PMSL

The error growth for all configurations is essentially the same (Fig 5.5) and will be dominated by the large-scale which is largely determined by the driving (LAM) model. There is some evidence that the largest domain (test3) is more in error particularly at longer forecast range.

Precipitation (Spanish plume cases only)

The precipitation accumulated over the three hours prior to 12Z, 15Z, 18Z and 21Z on 6/6/97 were derived from the Nimrod archives. These were then used to verify the corresponding forecast accumulated precipitations for the Spanish Plume cases using the NWP objective precipitation verification system (Anderson, personal communication). Four scores were calculated for each run at each validity time: the Hit Rate, the False Alarm Rate, the Equitable Threat Score and the RMS Factor. The results for Case 1 (DT 12Z), using a precipitation threshold of 0.1mm in 3 hours, are shown in Fig 5.6. No clear conclusion can be drawn, as the control is best for the HR, test3 is best for the FAR, and test5 is best for the RMSF! A similar (lack of) signal appears in the Case 2 results validated at the same times (Fig 5.7). Overall, the control gives probably the best results in these cases. Changing the precipitation threshold to 0.5mm in 3 hours (Figs 5.8 and 5.9) fails to discriminate any better between the runs.

6. Conclusions

The main conclusion from these (limited) tests is that there is no strong overwhelming evidence in favour of any of the test configurations. Generally higher resolution is beneficial for slightly better fog and surface temperatures. Also from these and previous tests there are sometimes improvement in detail for rainfall forecasts, but we have found no startlingly large impacts.

The "Spanish Plume" case has been rather confusing and a greater sample of cases is probably required to form definite conclusions on the merits of the southern boundary position. Subjectively, the greater domain for test3 and test5 appeared to be of benefit. A trial with full data extraction and assimilation over a larger domain should be more informative.

Since there is no strong signal from the tests the choice of area should be made on more pragmatic grounds and with a view to possible extra gains not apparent here. There has not been demonstrated a strong reason for the extension to south of the Pyrenees, test3, and in the cases here this was generally the (slightly) worse of the configurations. The choice is then between the highest possible resolution, test2, and the small extension in area south to ~44°N, test5. The difference in resolution between these is not great being just under and over 12km. In view of potential benefit from observations over France (and eventually continental radar data for possible

use in latent heat nudging) it would be better to opt for the slightly larger domain, test5. This domain is also not too great for Nimrod to be extended to cover the same area. There are advantages in using a common area for presentation of Nimrod and the mesoscale products and secondly for providing the input cloud analysis for MOPS at the higher resolution of 15km. If the mesoscale domain was larger then the cloud analyses would be at ~45km as currently supplied for the LAM.

References

Anderson, S — UK Precipitation Accumulation Verification. See: http://fr1000/~frsa/Precipitation_Verification_Form.html

Culverwell, I — Stage 2a Project Report. Available at http://fr0600/~fric/high_resolution/stage2a.html

Macpherson, B — Tests of latent heat nudging impact. See: http://fr0200:80/~frcc/row/1997_98/jun97/master.html#Bruce Macpherson